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Event-Related Potentials Elicited by Controlled and Automatic Target Detection

Report No. 8102

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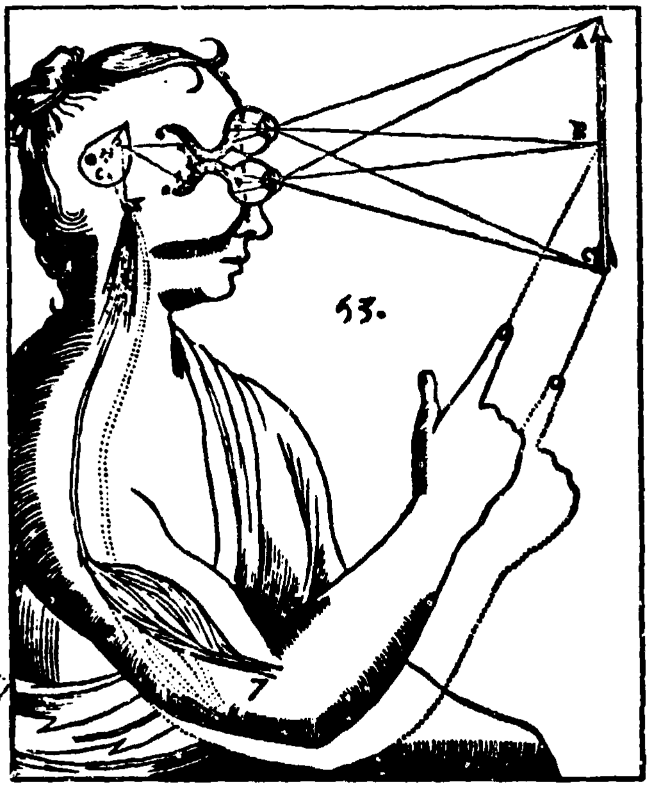

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When subjects search for the same set of targets over many trials (a training schedule known as consistent mapping or CM), performance can become relatively independent of processing load (defined as the product of the number of targets to be searched for and the number of forms in the display). Search is said to be "automatic." In contrast, when the role of distractors and targets is periodically exchanged, search speed is slow and highly dependent on processing load. Search occurring under these varied mapping (VM) conditions is referred to as "controlled." SEE OVER

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Subjects searched for CM and VM targets. ERP's were recorded from frontal (Fz) and parietal (Pz) electrodes both at the beginning and end of a 7 session training period. A large P300 component was observed at Pz in both search tasks with amplitude measurements independent of whether mapping was consistent or varied.

In contrast, mapping was related to an "early" component of the ERP (N1-P2). Under high processing load, a CM target produces additional negativity which may reflect orienting to the target's spatial location.

These results suggest that limited capacity decision making resources play a role in automatic detection. The advantage of consistent mapping training appears to lie in increasing discrimination between targets and distractors which in turn allows for efficient allocation of attention to target display areas.

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Abstract

When subjects search for the same set of targets over many trials (a training schedule known as consistent mapping or CM), performance can become relatively independent of processing load (defined as the product of the number of targets to be searched for and the number of forms in the display). Search is said to be "automatic." In contrast, when the role of distractors and targets is periodically exchanged, search speed is slow and highly dependent on processing load. Search occurring under these varied mapping (VM) conditions is referred to as "controlled."

The present study attempted to determine whether the high speed search process resulting from CM training occurs without the investment of a limited capacity attention system. The P300 component of the human event related potential (ERP) has been shown to be a sensitive index of the attention required by a variety of tasks. If CM training results in a withdrawal of attention, then CM target detection should be accompanied by smaller P300's than VM detection.

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The ability to perform more than a single task at a time depends critically on the level of experience associated with each task. Indeed, truly expert levels of skill, which depend on massive amounts of practice, often result in remarkable "time-sharing" performances. Pairs of complex tasks may be combined without mutual interference as in the case of piano playing and prose shadowing (Allport, Antonis, & Reynolds, 1972), typing and prose shadowing (Shaffer, 1975), and oral reading combined with written dictation (Hirst, Spelke, Reaves, Cabarack, & Neisser, 1980).

These results are often taken as evidence that extensive training in an activity may result in that activity becoming "automatic." Automatic mental activities presumably do not draw on the subject's limited pool of processing resources (Kahneman, 1973) so that an automatic task may be combined with another attention-demanding activity without mutual interference.

An alternative view of skilled behavior is that training results in efficient memory structures that allow observers to encode large amounts of information and produce sequences of action. For example, chess masters can quickly encode briefly presented pictures of standard chess configurations (Chase & Simon, 1973). Similarly, mnemonic strategies can produce short-term memory spans of 80 digits or more (Chase & Ericsson, 1978). Attention may still be invested in these encoding operations; it is the efficiency of the underlying representation that guarantees a good return on this investment.

These two views of skilled performance can be contrasted for the skill of visual target detection. For this skill, both the characteristics of "automatism" and the conditions leading to this stress state have been thoroughly explored by Schneider and Shiffrin (1977). Their subjects were required to determine whether anyone of m possible target was present in a visual display containing d characters. The display contained either 0 or 1 target with the remaining characters serving as distractors.

In one training schedule, known as <u>consistent mapping</u> (CM), targets and distractors never exchanged roles. After extensive training, detection latency became relatively independent of processing load (defined as the product of m and d), suggesting a parallel search. In contrast, <u>varied mapping</u> training (VM) in which targets and distractors periodically exchanged roles, produced detection latencies that were highly dependent on processing load.

Schneider and Shiffrin suggest that CM training results in "automatic processing" which is characterized as being fast, inflexible, and not requiring attention. VM training results in "controlled processing" which is slow, under subject control, and highly dependent on voluntary attention, especially in the form of comparison and decision processes in working memory.

Hoffman and Nelson (1981) investigated the attention demands of "automatic processing" by pairing a highly trained visual detection task with another concurrent visual discrimination task. They found that both the accuracy and speed of the automatic task suffered in the dual task situation. Subjects were able to improve their detection performance only at the cost of decreased performance on the concurrent task. Hoffman and Nelson suggested that automatic detection depends on comparison and response execution routines available in working memory. This resource may have to be shared by both tasks leading to a decrement in performance in dual task conditions.

A second source of inter-task interference did not depend on instructions to favor one or the other task. Performance on the concurrent task suffered in the presence of automatic targets even when such targets were to be ignored. Apparently, automatic targets trigger a shift of spatial attention to their display region. Other experiments showed that preventing this attention shift from occurring interfered with target detection.

These results suggest that extensive training in a visual detection task does not eliminate the need for access to limited capacity resources. A direct comparison of automatic and controlled detection tasks indicates that they rely on working memory to about the same extent (Hoffman & Nelson, 1981). The speed and accuracy of automatic detection may depend on the ability of automatic targets to quickly "capture" needed resources.

The present research was designed to provide converging evidence for this view through use of the event-related potential (ERP). The amplitude of the P300 component of the ERP has been found to be a sensitive index of the capacity utilized by perceptual discriminations (Israel, Chesney, Wickens, & Donchin, 1980; Israel, Wickens, Chesney, & Donchin, 1980). In addition, its peak latency increases with increases in processing load in VM detection tasks (Gomer, Spicuzza, & O'Donnell, 1976) suggesting that this component reflects some aspects of the comparison and decision processes in working memory (Donchin, Ritter, & McCallum, 1978). If both automatic and controlled detection require this resource, then both kinds of detection should produce substantial P300's.

ERP components that occur earlier than P300 are also of interest in the present study. Hoffman and Nelson (1980) assumed that the ability of automatic targets to interfere with the performance of other concurrent visual discriminations reflected competition for processing resources prior to working memory. Such a process should, therefore, be reflected in an ERP component earlier than P300. A promising candidate is the N2 component with an onset latency of 100-200 msec. Large N2's are present for occasional "deviant" tones embedded in a tone sequence, an effect that Naatanen (1981) calls "mismatch negativity." When clearly deviant tones are presented and subjects required to count them, an additional, frontally focused negativity appears. Naatanen (1981) refers to this negative wave as "active N2" to distinguish it from the "passive" variety which occurs even if subjects are engaged in another task such as reading.

"Active N2" may represent an early allocation of attention to task-relevant targets. If so, it may reflect the same process that is responsible for the intrusive effects of automatic targets and we would expect such targets to be associated with the "active N2" component.

In summary, the present experiment was designed to investigate the resource requirements of automatic detection by examining the ERP's elicited in controlled and automatic detection tasks. Behavioral data (Hoffman & Nelson, 1981) suggest that both controlled and automatic detection tasks make extensive use of comparison and decision processes in working memory leading to the prediction of substantial P300 components for both search tasks. In addition, automatic targets trigger a rapid shift of the spatial attention system to their display area which might be reflected in "early" ERP components such as the N2.

Method

Subjects

Subjects were six right-handed male undergraduate students with normal or corrected to normal vision who were paid for participation. Subjects ranged in age from 19.0 to 21.9 years with a mean age of 20.2 years.

Apparatus and Stimuli

Visual displays were presented on a Tektronix 604 display monitor equipped with a P-15 phosphor and controlled by a Digital Equipment Corporation PDP-12 laboratory computer. Letters and digits were $.23^{\circ}$ high and constructed by illuminating the appropriate points in a 6 x 5 matrix. Each point had a luminous directional intensity of 2.8 x 10-7 cd on a dark background. The display screen was positioned approximately 65 cm from the subject and was viewed in a darkened room through a locally constructed viewing hood.

Recording System and Data Analysis

The electroencephalogram (EEG) was recorded from frontal (Fz) and parietal (Pz) electrode sites referred to the right mastoid. Beckman miniature silver-silver chloride electrodes affixed with Grass EC-2 electrode paste were used for both scalp and mastoid placements. The electro-oculogram (EOG) was recorded as a check for possible contamination of the EEG by eyeblink or vertical eye movement potentials. Beckman miniature electrodes were attached one-half inch above and below the right eye for recording purposes. To reduce skin resistance all electrode sites were prepared by cleansing the skin surface with alcohol and abraiding the epidermis. Spot checks indicated electrode resistances of under 10K ohms.

EEG and EOG were amplified with Grass Model 7P1F low level DC preamplifiers on a Grass Model 7D polygraph. The amplifier configuration provided a frequency bandpass of .08 to 40 Hz. Analog signals were recorded on a Vetter Model B FM magnetic tape recorder for subsequent computer analysis. The EEG and EOG records were digitized off-line on the PDP-12 every 16 msec. beginning 100 msec. prior to stimulus presentation and continuing for 1020 msecs. following stimulus presentation.

Procedure

The subjects' task on each trial was to identify whether a memorized target digit or letter was present in a test display. The display sequence was similar in each condition. Before every trial a single memory set target (letter or digit) was presented which remained in view until the subject initiated the trial by depressing a microswitch with the left hand. A trial consisted of the presentation of a fixation point in the center of the screen followed two seconds later by the appearance of the test display matrix. The test display had a duration of 100 msec. and consisted of four characters placed at the corners of an imaginary square centered on the fixation point. The distance of each character from the fixation point was 1.2^{o} of visual angle. A letter, digit or an irrelevant "%" symbol could appear in each of the four positions depending upon the display size and mapping condition for a particular block of trials.

In consistently mapped (CM) trials, the memory set target was randomly selected on each trial from the digit set, 0 through 9; distractors were randomly chosen from the letter set (B,C,D,F,G,H,J,K,L,M,N,P,R,S,T,V,W). In varied mapping (VM) conditions, both the memory set target and distractors were randomly chosen from the letter set. For display sizes of one item, the remaining three positions without a displayed letter or digit were filled with an irrelevant "%" mask. Targets appeared in half of the trials in each condition and were randomized within each block. The assignment of target letter/digit to positions in the display was random but equally balanced across the four positions.

Concurrent with the visual display, a tone (1200 Hz, 65 dB SPL, 25 msec. rise/fall time) was presented through earphones. All stimuli were presented on a background of continuous white noise (52 dB SPL) which served to mask extraneous external noise.

Upon presentation of the visual display the subject was required to respond yes/no to indicate the presence or absence of the memory set target in the test display by depressing one of two microswitches with the right hand. Subjects were instructed to respond as quickly as possible while maintaining high accuracy. Following termination of the display the screen was blank for 2 seconds at which point feedback concerning response accuracy and reaction time for that trial were presented.

To summarize, four different types of blocks were used in this study each with a memory set size of one item: Consistently mapped with a display size of one (CM-1) or four (CM-4); varied mapped with display sizes of one (VM-1) or four (VM-4).

Each subject served in eight sessions with four blocks of 96 trials per session. The first two sessions were considered practice and familiarized the subjects with the tasks and recording apparatus. Sessions 3-6 were devoted to CM training. Within each session the subjects were given two blocks each of CM-1 and CM-4 in random order. Session 7 and 8 were both recorded (EEG and EOG). In Session 7 subjects were given two blocks each of CM-1 and CM-4 while in Session 8 they received two blocks each of VM-1 and VM-4.

RESULTS

Reaction Times

Figure 1 shows reaction times and error rates as a function of display size, mapping, and target-present/absent. An expected, CM training led to faster search times than VM training, $F(1,5) = 22.9$, $p < .009$. Also consistent with previous findings in visual search, target-present displays were faster than target-absent displays, $F(1,5) = 22.9$, $p < .001$. The main effect of display size was significant, $F(1,5) = 16.1$, $p < .01$. None of the interaction were significant.

Insert Figure 1 about here

Event-Related Potentials

P300 Latency

Figure 2 shows event related potentials averaged over subjects. In order to assess the effect of experimental variables on P300 latency, a peak

Insert Figure 2 about here

analysis was conducted. The P300 peak was defined as the point of maximum positivity in a "window" extending from 284 to 604 msec. post-stimulus. These parameters were determined from an examination of the grand mean waveform for the entire experiment.

Figure 3 shows that, in agreement with the RT data, P300 latency is slower with the larger display size, $F(1,5) = 19.0$, $p < .008$. There is a

Insert Figure 3 about here

suggestion that P300 is faster for target-present displays than for target-absent conditions but this effect failed to reach significance, $F(1,5) =$

3.79, $p < .10$. Interestingly, mapping, which had a large effect on RT appears to have negligible effects on P300 latency, $F(1,5) < 1$.

P300 Amplitude

Figure 4 shows P300 amplitude as a function of mapping, display size, and target-present/absent. Both consistent and varied mapping produced large P300 components of about the same size, $F(1,5) < 1$. Amplitudes were larger

Insert Figure 4 about here

when display size was small $F(1,5) = 7.9$, $p < .04$ and when the target was present in the test set $F(1,5) = 16.8$, $p < .03$.

The ERP waveforms were submitted to a principal components factor analysis (BMD program BMDP4M) on the covariance association matrix. This analysis included 96 ERP corresponding to a factorial combination of 6 subjects, 2 electrode sites, 2 mappings, 2 display sizes, and 2 response types. The dependent variables were 64 deviation scores formed by subtracting successive post-stimulus voltage measurement from an average of the pre-stimulus values. Four factors with eigenvalues greater than 1 were extracted and rotated to varimax criterion. Figure 5 illustrates the loadings of the 64 time points on these factors.

Insert Figure 5 about here

Factor 2 is clearly a P300 factor. Its latency is similar to the latency of P300 contained in the grand mean and an analysis of variance on the component scores revealed this factor to be larger at Pz than Fz, $F(1,5) = 14.5$, $p < .01$. An interaction of electrode site and target-present/absent, $F(1,5) = 6.7$, $p < .05$ indicated that P300 was larger for target-present displays than target-absent displays. Increasing display size resulted in a reliable reduction in component amplitude F (1,5) = 2.99.2, p < .01. The effect of mapping was not significant, F (1,5) = 2.1, p < .2. These findings are similar to the results of the P300 peak analysis described above. The principal result of both analyses is that CM and VM training schedules are associated with substantial P300 components but mapping has virtually no effect on P300 amplitude.

N1-P2 Amplitude

Factor 4 in the principal components analysis has its maximal loadings in the range of 120-160 msec. post-stimulus which is the approximate latency of the N1-P2 complex. Statistical analysis performed on the factor scores and N1-P2 amplitude measures produced similar results. The N1-P2 component analysis revealed a significant interaction of mapping, display size and

Insert Figure 6 about here

target-present/absent, F (1,5) = 7.9, p < .04. This interaction is depicted in Figure 6. N1-P2 amplitudes decreased as display size was increased from 1 to 4 for target-present displays under consistent mapping. Display size had negligible effects for all other conditions.

N2 Amplitude

N2 amplitudes are smaller for target-absent displays than target-present displays, F (1,5) = 8.2, p < .04. This "mismatch negativity" apparent in the Fz recording may be partly responsible for the smaller P300's observed at Pz for target-absent displays. In order to further evaluate the temporal and topographical characteristics of this mismatch negativity, "difference curves" were computed by subtracting, for each condition, the target-present ERP's form the target-absent ERP's. These difference curves are shown in Figure 7. Target-absent displays are associated with increased negativity relative to

Insert Figure 7 about here

target-present conditions. This negative component has an onset at about 200 msec. for all conditions and is similar in shape for both recording sites. The difference in baseline for target-present vs. absent conditions in the display size 4-CM condition is responsible for this curve falling below the zero point. This shift in baseline accounts for the smaller N2 observed in this condition.

DISCUSSION

The present experiment examined the event-related potentials (ERP's) elecited by controlled and automatic detection tasks. Allowing subjects to search for the same set of targets over several sessions (consistent mapping training or (CM) produced search times that were reliably faster than detection under varied mapping (VM) training, in agreement with the results of Schneider and Shiffrin (1977).

The principal question addressed by this study was whether the decrease in search times produced by consistent mapping training is a reflection of a decreased involvement of limited capacity resources in the detection process. This position would suggest that P300 amplitude, which is sensitive to the perceptual resources required by a task, (Israel et al., 1980 a,b), would be smaller for CM detection than VM detection. The present study, however, found no effect of mapping of P300 amplitude, suggesting that training did not reduce the need for the comparison and decision-making processes reflected by P300. Even P300 latency was independent of mapping, suggesting that the faster detection times for CM detection obtained in the present study may be due to processes occurring after the decision regarding the presence or absence of the target. One possibility is that one of the benefits of CM training is faster organization of responses following the outcome of the decision process.

In contrast to the lack of any effect of mapping on the P300 component, an "early" component of the ERP, the N1-P2 amplitude, was affected by mapping. The presence of a CM target resulted in a smaller N1-P2 amplitude compared to the target-absent condition. This effect only occurred when the target was embedded in a display of confusable distractors and did not occur for VM targets.

The additional negativity associated with the occurrence of CM targets may be a reflection of "rapid allocation" of attention to the spatial position of the target. The dependence of this effect on processing load is consistent with other reports regarding this "processing negativity" (Hillard, 1981). Other investigators (Schwent, Hillyard, and Galambos, 1976; Parasuraman, 1978) have found that the additional negativity associated with attended inputs is dependent on a high rate of information delivery and may be absent altogether at slower presentation rates.

Both detection tasks produced mismatch-negativity (Naatanen & Michie, 1979). Target-absent displays were associated with additional negativity relative to target-present displays. This mismatch negativity had an onset at approximately 200 msec. and was present at both the Fz and Pz recording sites. Mismatch negativity has usually been associated with deviant stimuli occurring in a repetitive set of background stimuli. The fact that it can occur for mismatches between subject generated templates and sensory inputs suggests that this component may have general applicability beyond orienting tasks for studying human pattern recognition.

Conclusions

The results of the present ERP study converge with the behavioral observations of Hoffman and Nelson (1981) in suggesting that consistent mapping training in a target detection task does not result in the withdrawal of attentional resources from that task. Instead, it appears that CM training results in increasing discriminability of targets and distractors allowing for a rapid allocation of attention to the spatial position of the target. The rapid allocation of needed resources may be the principal process underlying skilled performance in detection tasks.

While the present results suggest quite clearly that automatic detection (CM) produces P300 amplitudes which do not differ from those obtained under controlled detection (VM), these conclusions must be tempered by the finding that subjects still showed nonzero slopes at the end of training suggesting that although CM training resulted in faster RT's than did VM training, subjects may not have been completely automatic. We are currently pursuing this question using more extensive training schedules. Preliminary data from five subjects who have obtained flat slopes in CM training conditions indicate equivalent P300 amplitudes for both detection tasks, in agreement with the present data.

Because of the similarity of slopes for CM and VM search in experiment one, we could not be sure that subjects had become "automatic" in the CM condition. We have run a second group of subjects in the same experiment with the following changes. Memory set size was two and, in the case of CM search, subjects searched for the same set of two digits. Training in the CM task continued until each subject's slope was less than 10 msec/comparison. At this point, ERPs were recorded for both CM and VM detection.

Figure 8 shows reaction time as a function of display size, mapping, and target-present/absent. Two features of these data indicate that CM and VM training have resulted in the two search modes that Schneider and Shiffin (1977) call automatic and contrasted. First, for VM training, target-absent slopes are larger than target-present slopes, while for CM training, they are the same. Second, CM slopes are virtually flat while VM search is significantly slower for larger processing loads. These findings are similar to those originally reported by Schneider and Shiffin.

Figure 9 shows the event-related potentials as a function of display size, target-present/absent and recording site for both mapping conditions. The principal result to note is these data are the large P300 components associated with CM search. The amplitude of P300 for CM detection is at least as large as the P300 associated with VM detection. The smaller P300s associated with VM detection may be partly due to greater latency variability. We have applied a latency adjustment procedure to these data for two subjects and found equivalent P300 amplitude for CM and VM search.

These preliminary data are in agreement with the data from experiment 1 in showing that both CM and VM detection tasks are utilizing limited capacity processes as reflected in P300 amplitude.

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FIGURE CAPTIONS

Figure 1. Average reaction time and error rates as a function of display size (1 or 4), mapping (CM or VM), and presence (+) or absence (-) of target.

Figure 2. Average event-related potentials as a function of display size, mapping, and presence/absence of target for Fz and Pz recording rates. Stimulus onset shown by tick mask.

Figure 3. Average P300 latency at Pz as a function of display size, mapping, and presence/absence of target.

Figure 4. Average P300 amplitude at Pz as a function of display size, mapping, and presence/absence of the target.

Figure 5. Varimax-rotated component loadings for the first four components extracted from a principal component analysis of ERPs.

Figure 6. N1-P2 amplitude as a function of display size, mapping, and presence/absence of the target.

Figure 7. The difference between target-present and target-absent ERPs (target-absent-target-present) as a function of mapping and display size for frontal and parietal recording sites. ERPs were digitally filtered (half-power cutoff frequency of 3.9 hz) before subtraction. Note the similar onset time of the "difference wave" for all conditions and both recording sites.

Figure 8. Preliminary data from experiment 2. Average reaction time as a function of display size, target-present/absent, and mapping.

Figure 9. Preliminary data from experiment 2. Average event-related potentials as a function of display size, mapping, and target-present/absent for FZ and PZ recording sites.

FOOTNOTE

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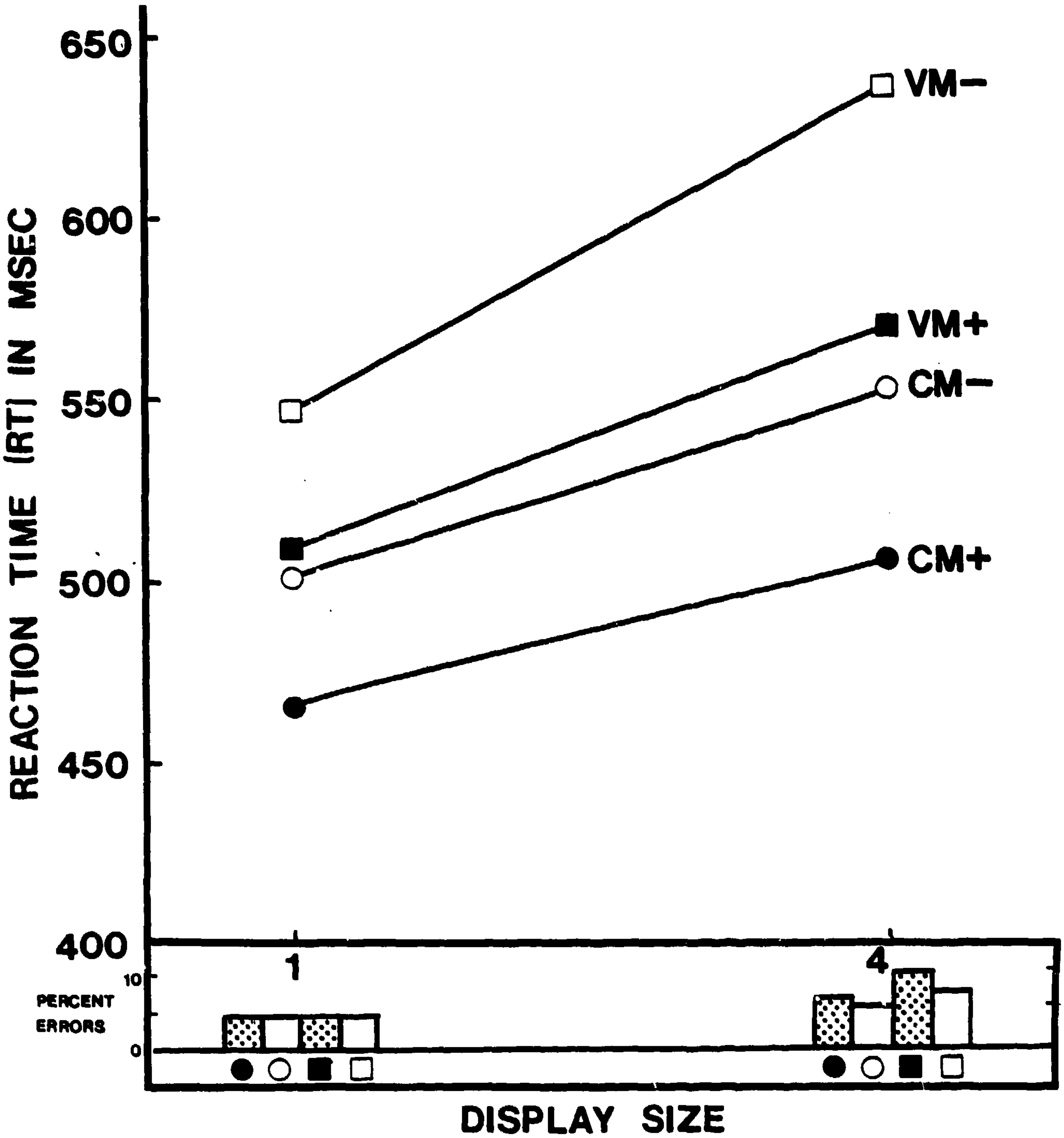

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Figure 1

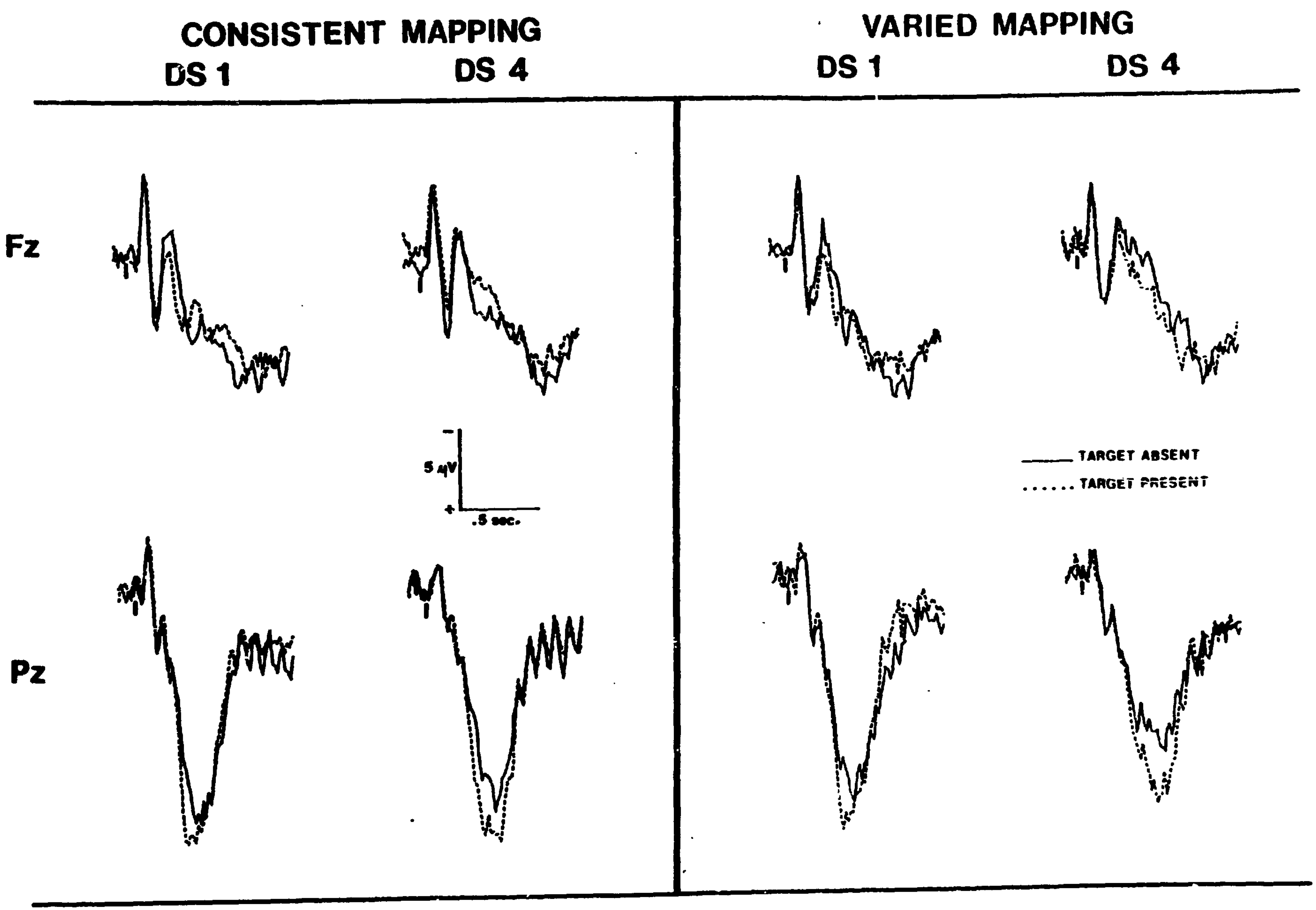
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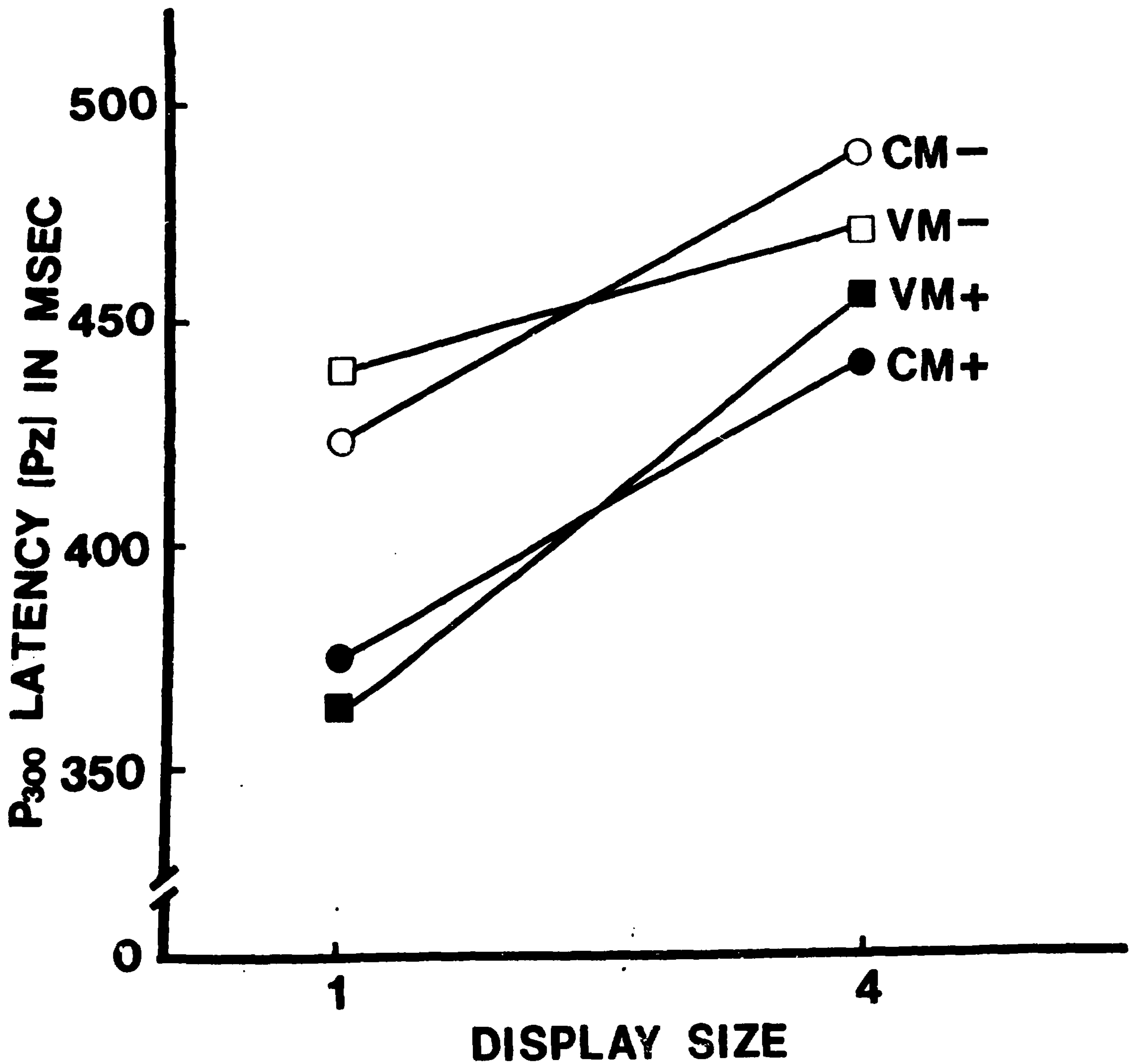
Figure 2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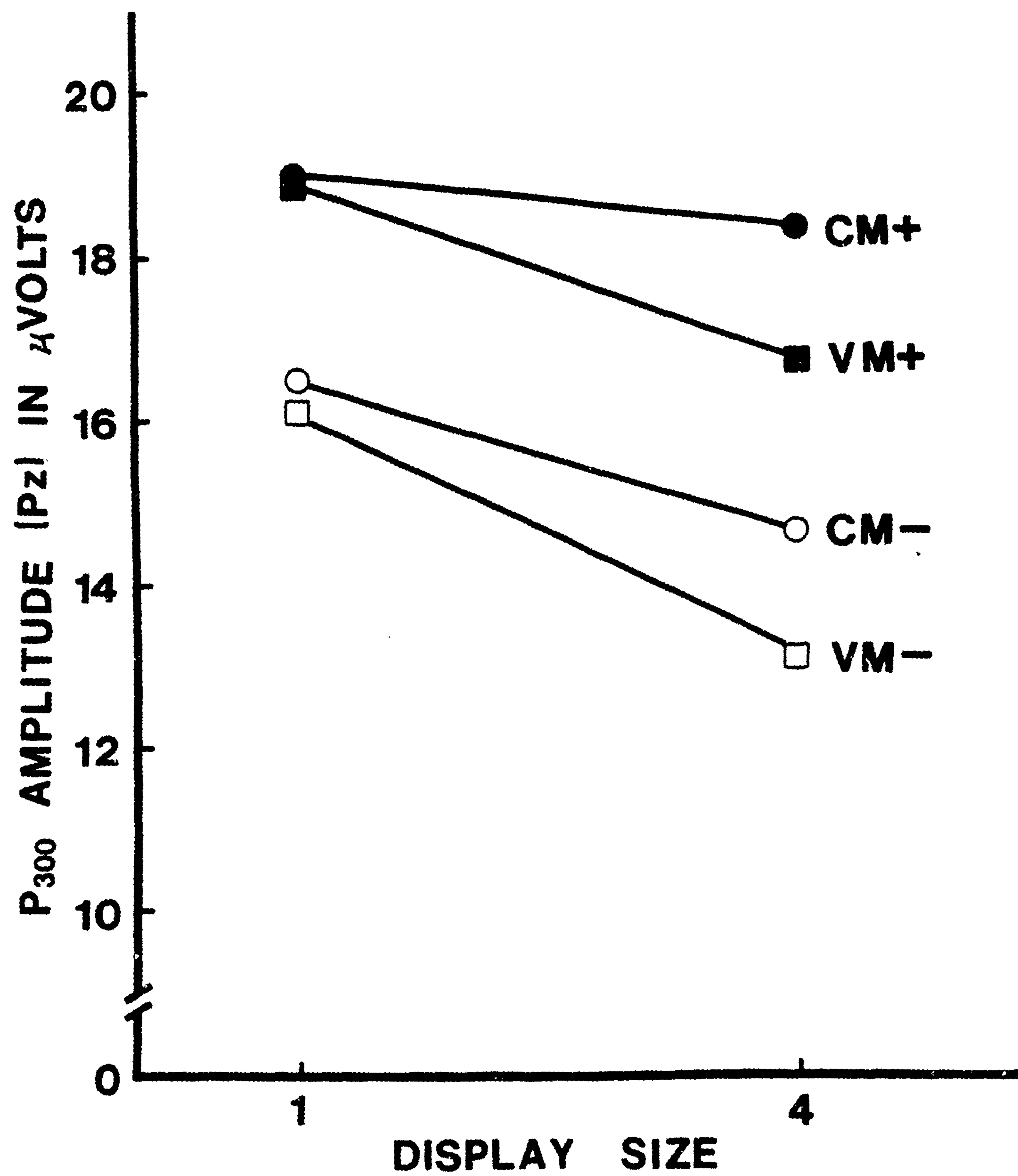
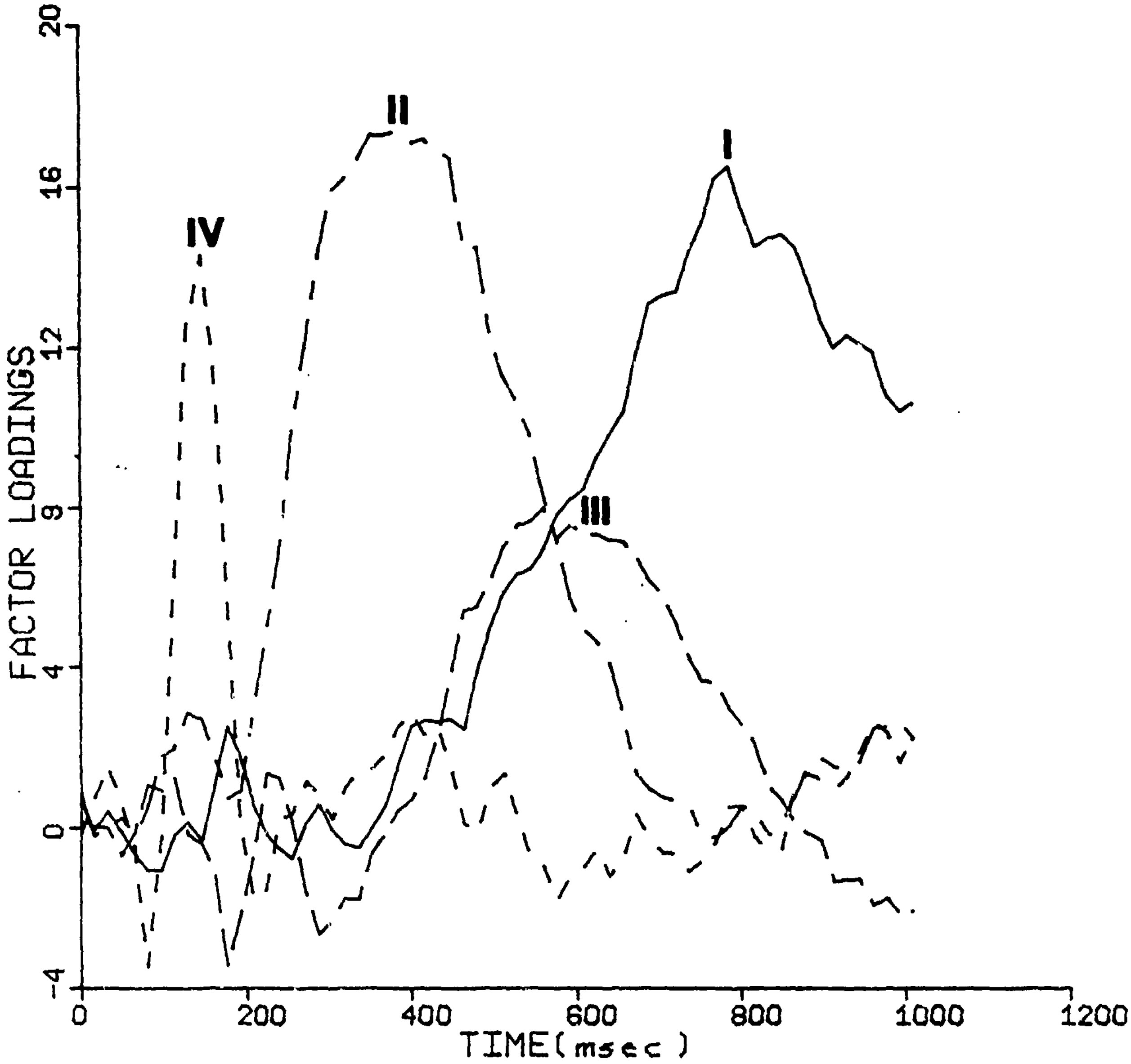
CM+

Figure 3



20
18
16
14
12
10
0
1
4
DISPLAY SIZE
P_{300} AMPLITUDE (Pz) IN µVOLTS
CM+
VM+
CM−
VM−

Figure 4



II
I
IV
III
FACTOR LOADINGS
-4
0
4
9
12
16
20
0
200
400
600
800
1000
1200
TIME(msec)

Figure 5

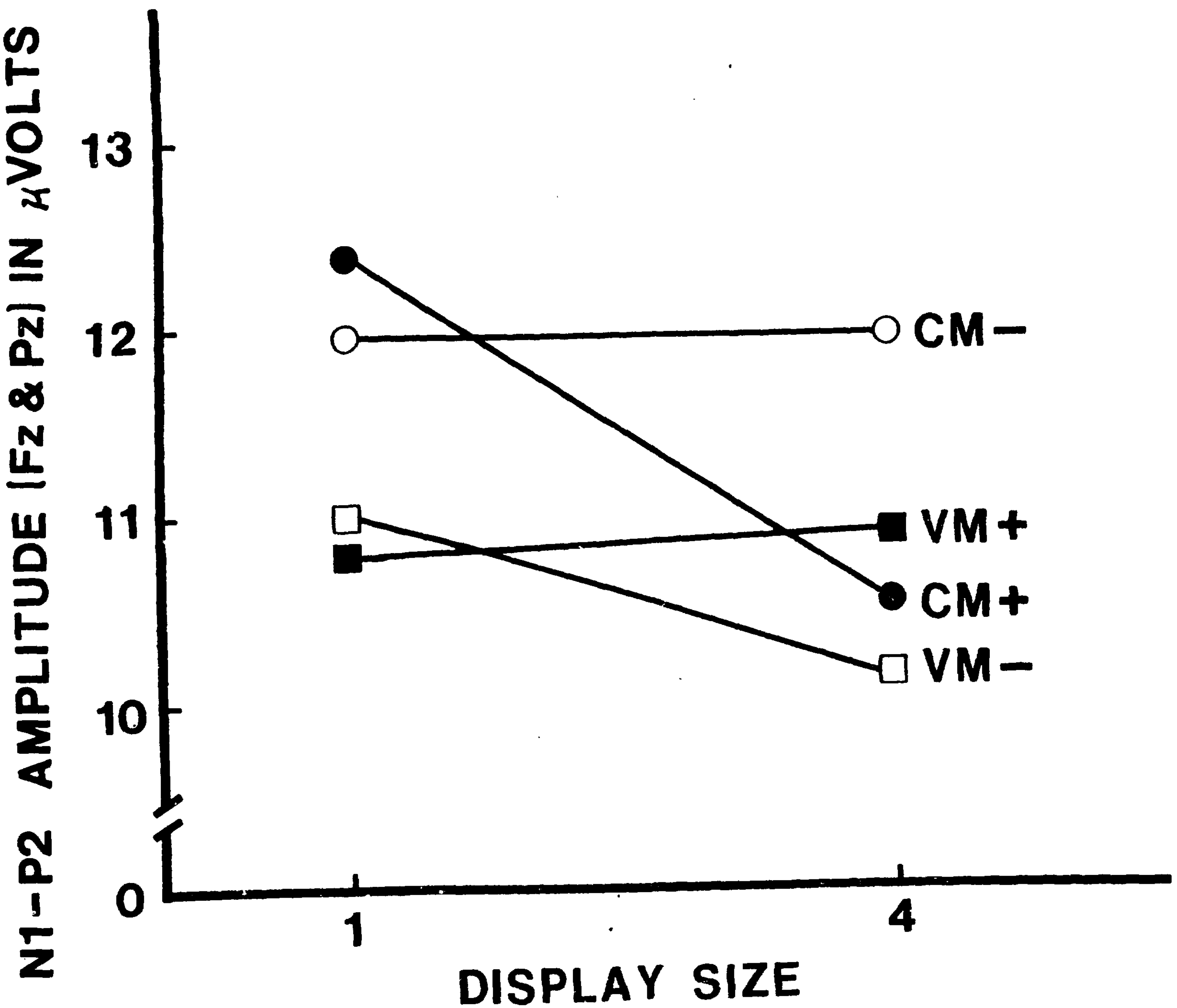

N1-P2 AMPLITUDE (Fz & Pz) IN μVOLTS
13
12
11
10
0
1
4
DISPLAY SIZE
CM−
VM+
CM+
VM−

Figure 6

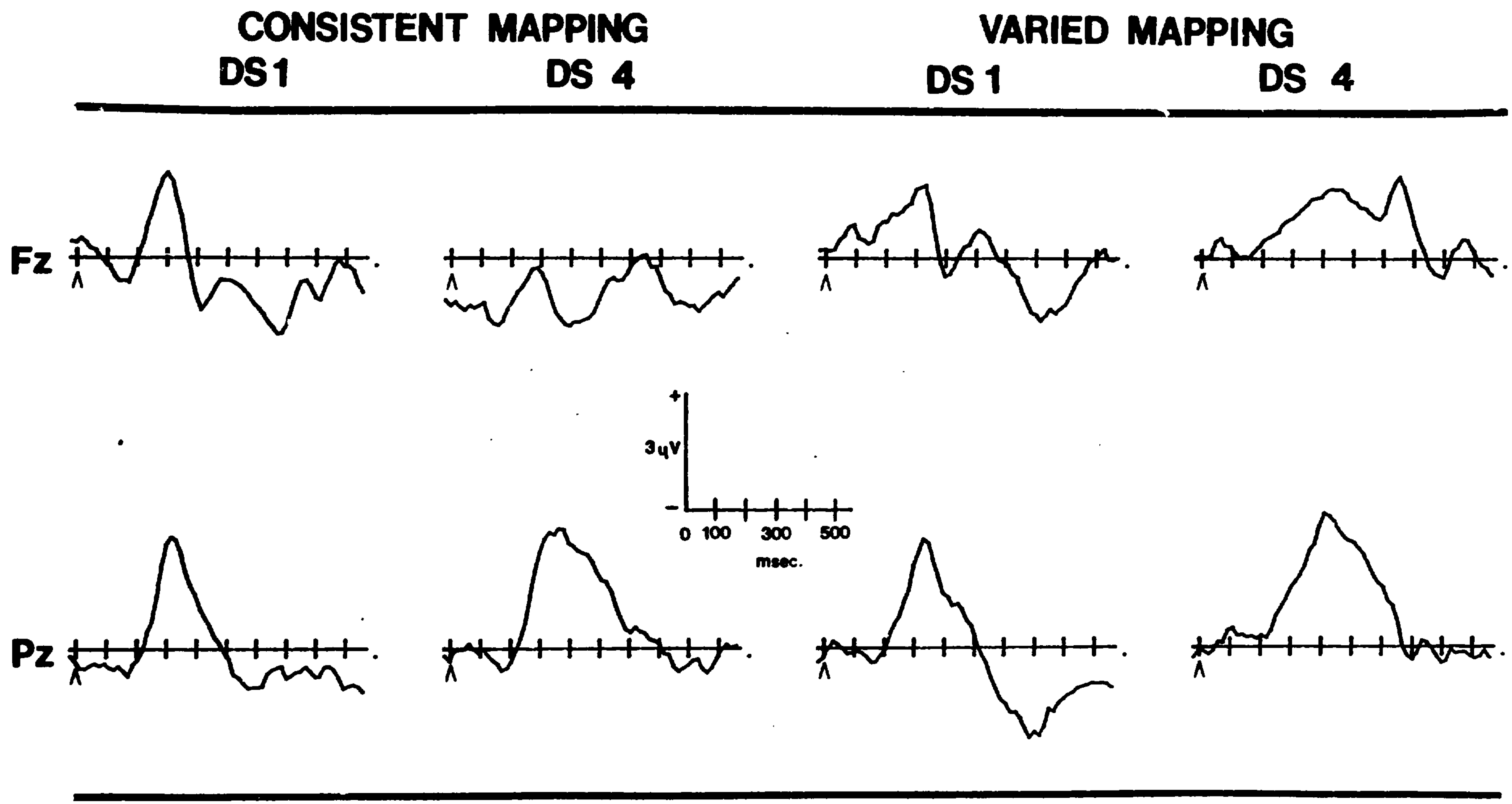

CONSISTENT MAPPING
DS1
DS 4
VARIED MAPPING
DS 1
DS 4
Fz
Pz
+
3μV
-
0 100 300 500
msec.

Figure 7

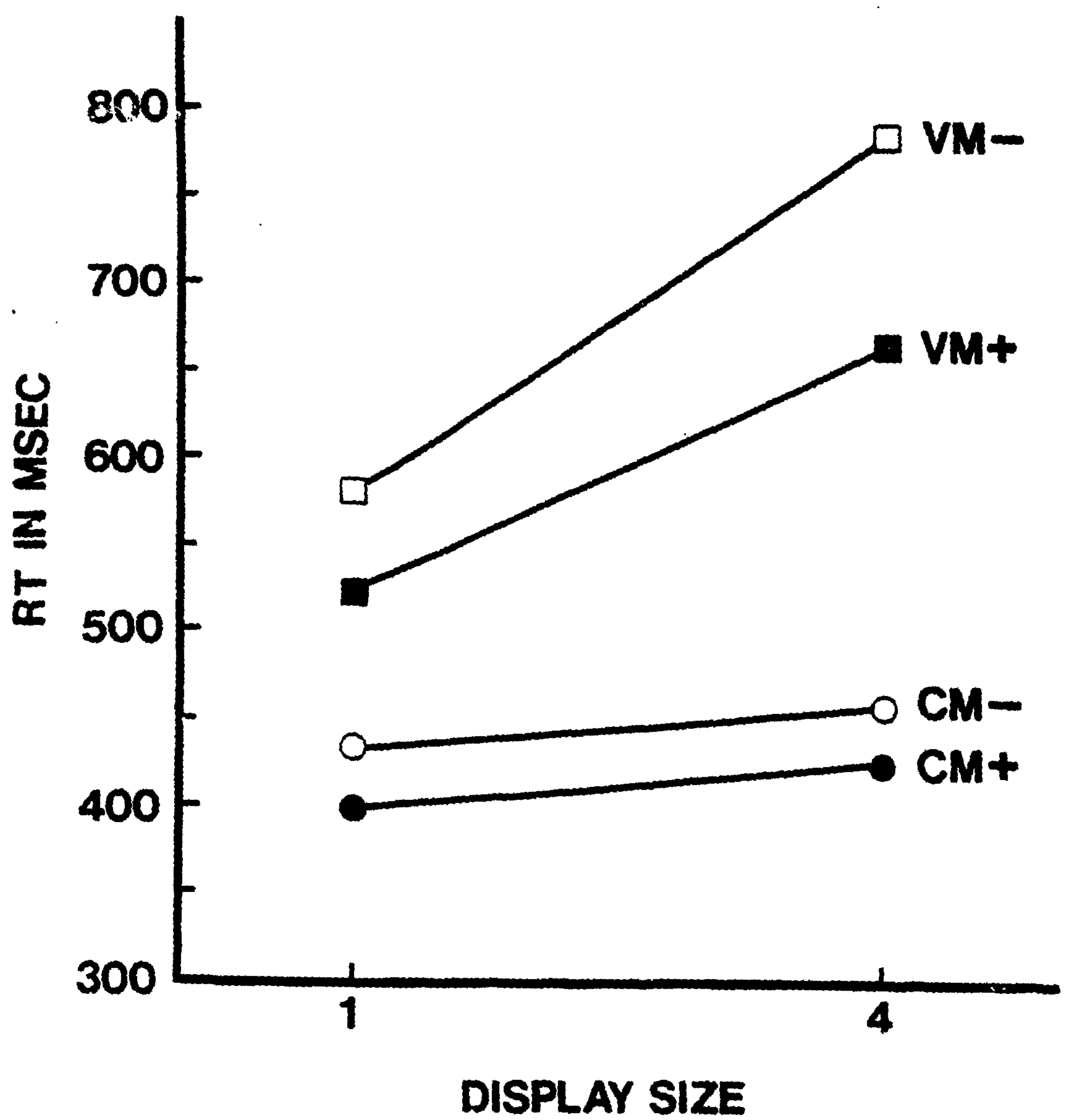
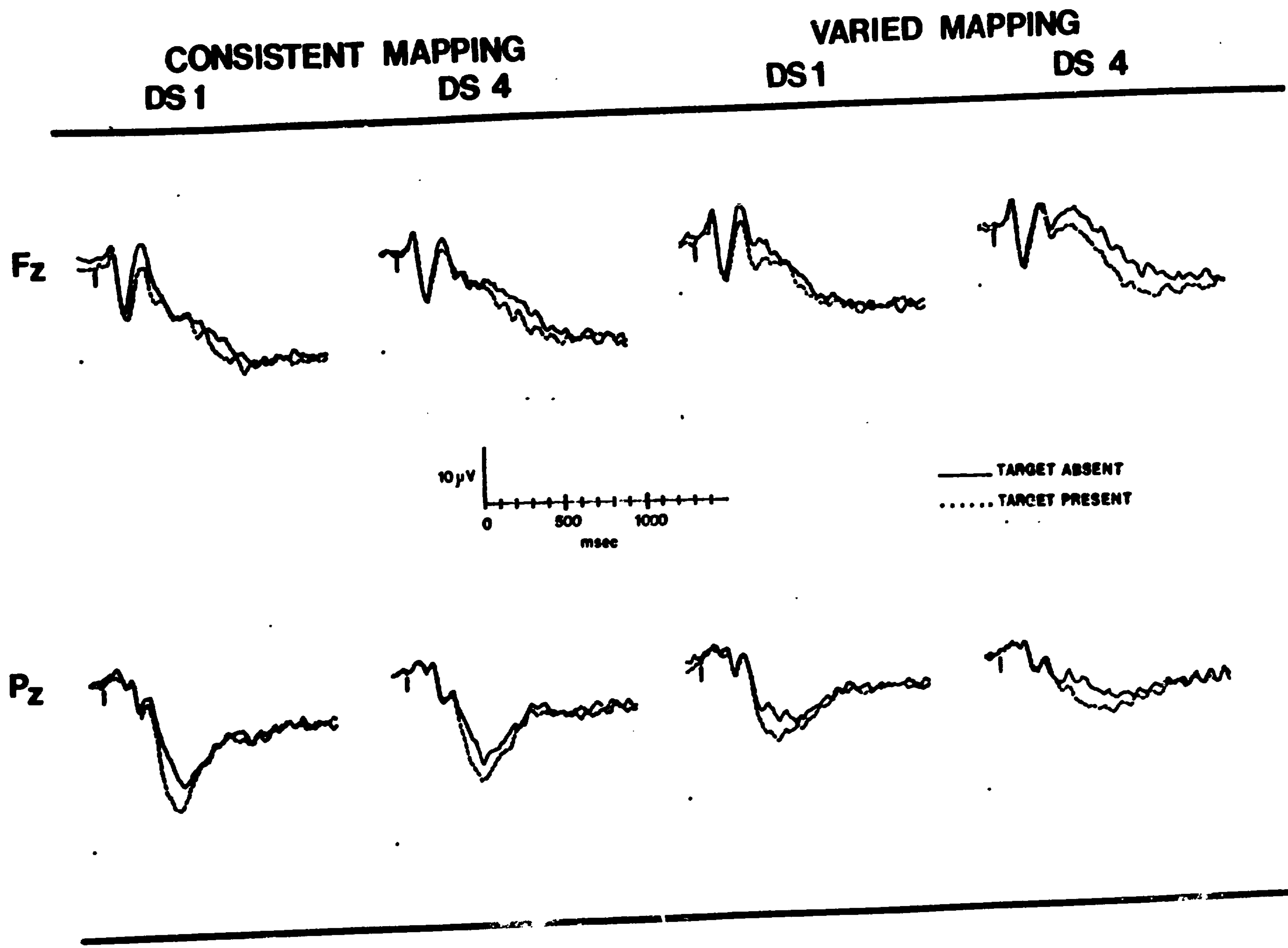


Figure 8


CONSISTENT MAPPING
DS 1
DS 4
VARIED MAPPING
DS 1
DS 4
Fz
Pz
10 μV
0
500
1000
msec
TARGET ABSENT
TARGET PRESENT

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